# ENERGY USE IN FREIGHT TRANSPORTATION

*Staff Working Paper*

February 1982

CONGRESSIONAL BUDGET OFFICE
U.S. CONGRESS
WASHINGTON, D.C.

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The Congress of the United States
Congressional Budget Office

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# ERRATA SHEET

## ENERGY USE IN FREIGHT TRANSPORTATION

Page 39 should follow page 41.

## PREFACE

The use of energy by the major modes of freight transportation has become of increasing concern in setting transportation policy. This report complements previous Congressional Budget Office (CBO) studies of the relative energy efficiency of the major modes of urban passenger transport and of intercity passenger transport. It was prepared at the request of the Commerce, Transportation and Tourism Subcommittee of the House Committee on Energy and Commerce. In keeping with CBO's mandate to provide objective and impartial analysis, the study offers no recommendations.

Richard R. Mudge of CBO's Natural Resources and Commerce Division prepared the study under the supervision of Damian J. Kulash and David L. Bodde. Valuable comments were received from representatives of the Association of American Railroads, the American Trucking Association, the Coal Slurry Pipeline Association, and the National Waterways Conference, and from the following individuals: Axel Rose of Oak Ridge National Laboratory, Edward Gregory of the Department of Energy, John Pollard of the Transportation Systems Center, and Samuel E. Eastman. Other suggestions came from Peter Tarpgaard, Allen Kraus, and Richard Weissbrod of CBO. Francis Pierce edited the manuscript and Kathryn Quattrone prepared the paper for publication with help from Paula Mills.

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## SUMMARY

This report examines the relative energy efficiency of the different modes of freight transportation. It finds that in terms of energy per ton-mile, oil pipelines are easily the most efficient of the modes of transportation considered. Inland barges rank second, although for some uses railroads are of comparable efficiency. Trucks use more energy than railroads, and cargo planes are at the bottom of the efficiency range (see Summary Table). But these simplified comparisons must be modified in several ways.

### Modifying Factors

Oil pipelines use only 500 BTUs (British Thermal Units) per ton-mile (280 ton-miles per gallon of diesel fuel), but they are limited by their very specialized function. The efficiency of inland barges (990 BTUs per ton-mile or 140 ton-miles per gallon on average), is likewise offset by the roundaboutness or circuity of most rivers. Also, significant amounts of energy may be required to bring cargo to a waterway system: grain and other farm products are sometimes trucked 200 miles to a river, increasing energy use per ton-mile by 50 percent or more.

The efficiency of rail transportation varies considerably depending on the commodity and the level of service provided; at one extreme, unit trains designed to carry only coal typically require less than 900 BTUs per ton-mile of cargo (155 ton-miles per gallon), while at the other extreme high-speed short trailer-on-flat-car (TOFC) trains use about 2,000 BTUs per ton-mile of cargo (68 ton-miles per gallon).

Intercity trucks require on average about 3,400 BTUs per ton-mile of cargo (41 ton-miles per gallon), twice the rail average and 1.7 times that for rail TOFC. It is not surprising that trucks require more energy since they provide a generally higher level of service than rail.

An even higher level of service, and hence greater energy need, is characteristic of air freight. In planes devoted to air freight, over 28,000 BTUs per ton-mile of cargo may be required (5 ton-miles per gallon), although freight carried in the belly of a passenger plane may require only 3,900 BTUs per ton-mile of cargo (35 ton-miles per gallon).

A specialized new mode of freight transportation is the coal slurry pipeline; this appears to require about 1,270 BTUs per ton-mile of coal--although this conclusion is based largely on engineering studies.



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SUMMARY TABLE 1. ESTIMATES OF TYPICAL FREIGHT ENERGY EFFICIENCY (In BTUs per ton-mile of cargo)

| Mode | Modal Energy a/ |
|---|---|
| Rail - Overall | 1,720 |
| TOFC b/ | 2,040 |
| Unit coal train | 890 |
| Truck | |
| Average intercity | 3,420 |
| Barge - Overall | 990 |
| Upstream | 1,280 |
| Downstream | 620 |
| Air | |
| All-cargo plane | 28,610 |
| Belly freight | 3,900 |
| Oil Pipeline | 500 |
| Coal Slurry Pipeline | 1,270 |

a/ Combines propulsion energy, maintenance energy, vehicle manufacturing energy, construction energy, and the effect of circuity, as well as refinery losses and the energy used for empty movements and for the non-cargo weight of vehicles. One gallon of diesel fuel contains on the average 138,700 BTUs (British Thermal Units) of energy, and a gallon of gasoline 125,000 BTUs. A ton-mile represents the movement of one ton a distance of one mile.

b/ Trailer on flat car.

## Components of Energy Use

These energy estimates include all of the energy consumed in transportation--that is, not only the energy used in propelling a vehicle but also the energy used in manufacturing and maintaining it, and in building the guideway over which it moves. In addition, they make allowance for "circuity"--the extent to which a vehicle's route departs from a straight line. The amounts of energy used for propulsion and for circuity are by far the most important, accounting between them for more than 70 percent of the energy used by most modes of transportation.

For rail and barge transportation, propulsion consumes between 35 and 50 percent of all energy used. For intercity trucks, propulsion accounts for about 60 percent, and for airlines about 90 percent, of total energy use. Circuity requires about 45 percent of barge energy, 35 percent of rail energy, and 20 percent of intercity truck energy, the differences corresponding largely to the extent of each mode's transport network. On the other hand, circuity accounts for less than 10 percent of energy use by airlines and pipelines. With a few exceptions, none of the other components of energy use--vehicle manufacture, guideway construction, and maintenance--accounts for more than 10 percent of total energy use.

## Other Factors

Factors such as speed, terrain, and type of cargo have a major influence on energy use. For example, a train carrying only coal is much more efficient per ton-mile cargo moved than a mixed train carrying various manufactured goods in boxcars, many of them empty. Similarly, upstream barge traffic requires more energy than barges moving downstream.

Finally, energy is only one of the concerns that enter into the setting of transportation policy. Of more importance, usually, are the total costs of each mode of transportation, the service qualities it possesses, the effects it may be expected to have on regional development, and the way in which it is financed.

# CHAPTER I. INTRODUCTION

Increasingly, debate in the Congress is shaped by concern over energy. This is particularly true for transportation, which accounts for a quarter of the nation's energy use and half of its petroleum use. The potential for energy savings has played a part in the debate over truck and rail deregulation, user fees on the inland waterway system, and federal aid to railroads, among other examples.

There is much disagreement as to the relative energy efficiency of different modes of transportation. Some spokesmen maintain that railroads offer the most energy-efficient means of transporting freight, and that in this they are four times as efficient as trucks. Others reply that barges on the inland waterways far exceed railroads in efficiency. Still others point to the recent improvements in motor vehicle economy and also argue that trucks provide a higher level of service than other modes. The debate is difficult to resolve because the parties use conflicting data and different analytical approaches.

This paper examines the available evidence as to energy efficiency for each mode of transportation in a systematic way in an effort to provide a basis for informed discussion. The comparisons are limited to the energy requirements of intercity freight transportation. 1/ (Local freight movement is not considered because Congressional actions focus on interstate commerce, and also because reliable data are lacking.) Of necessity, the emphasis is on average or typical conditions, and the results will have to be modified to fit differing circumstances. For example, in special geographical conditions, such as mountainous terrain, energy requirements may differ considerably from the average. Also, some of the longer-term considerations such as the amount of energy used in vehicle manufacture or guideway construction will not apply to analyses concerned with the short term.

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1/ Freight transportation uses 10 percent of total energy and over 20 percent of the nation's petroleum. In the future these fractions are likely to increase as improvements in automobile fuel economy outstrip foreseeable improvements in the various modes of freight transportation.

It is hardly necessary to add that energy is not the only criterion to be considered in setting transportation policy. In most circumstances it is probably not even the most important criterion. Others include cost and quality of service, equity, the needs of regional development, and the concern for environmental pollution.

Chapter II of the report describes the three measures of energy use that form the basic analytical framework. Chapter III presents the results of the analysis and discusses some of the policy implications. Appendix A provides a detailed description of the data. Appendix B lists the major sources.

## CHAPTER II. ANALYTICAL APPROACH

The energy efficiency of different modes of freight transportation may be compared on the basis of energy used per ton-mile of cargo carried. This is done by estimating the energy used (measured in British Thermal Units--BTUs) 1/ and dividing it by the tonnage carried times the route miles covered.

$$\text{Energy Efficiency} = \frac{\text{Total Energy Used (BTUs)}}{\text{Tons x Miles}}$$

The principal problem is that of estimating the total amounts of energy used. In comparing the long-term energy efficiency of, say, railroads and trucks, it is necessary to include not only the energy used in propelling the vehicles but that consumed in manufacturing them and in building the guideways (tracks and highways) on which they run, as well as in maintaining each system. The same holds for other modes of transportation such as canals, pipelines, and airlines.

In this paper the estimation of energy efficiency is carried out in three steps. First, operating energy is calculated--the energy required for vehicle propulsion divided by the average load. Estimates of average load must be adjusted for the amount of travel with no load (called empty backhauls). Energy losses during the refining process are incorporated as well.

The second step is to estimate line-haul energy. This adds to operating energy the energy used to maintain vehicles and guideways, the energy required to construct the guideways, and the energy used in vehicle manufacture. Estimates must also be made of the length of life of vehicles and guideways in order to allocate construction and manufacturing energy over their effective lives.

Third, the estimate of line-haul energy is modified to take account of the additional energy used in circuity or roundaboutness, and the energy used in access. Circuity is the amount of excess or unproductive travel used to move goods from one point to another, as compared with the theoretical

1/ One gallon of diesel fuel contains 138,700 BTUs, and a gallon of gasoline 125,000 BTUs.

minimum distance or great-circle route. Access energy is the amount of energy required to move the cargo to and from the system. The resulting measure (line-haul energy adjusted for circuity and access) is termed "modal energy." It is the most comprehensive measure of energy use in transportation. 2/ The analytical framework may be depicted as follows:

| Basic Energy Components | Measures of Energy Use | | |
|---|---|---|---|
| Propulsion energy per ton-mile | Operating energy | | |
| Terminal and maintenance energy | | Line-haul energy | |
| Guideway construction energy | | | |
| Vehicle manufacturing energy | | | Modal energy |
| Energy used in access | | | |
| Circuity | | | |

Many analyses of transportation energy efficiency consider only operating energy and fail to include the energy used in manufacture, construction, maintenance, circuity, and access. 3/

2/ A fuller description of this approach can be found in the Congressional Budget Office Background Paper, Urban Transportation and Energy: The Potential Savings of Different Modes (December 1977), Chapter II.

3/ For example, see Transportation Research Board, National Cooperative Highway Research Program, Energy Effects, Efficiencies, and Prospects for Various Modes of Transportation (1977).

## GENERAL MEASUREMENT PROBLEMS

Freight transportation modes cannot all be analyzed in exactly the same way. One reason is that there are differences in their typical cargos. One of the more significant variables is cargo density--a ton of television sets requires five to six times as much space as a ton of coal, for example. 4/ Many manufactured goods fill the space available before reaching the weight limit for the vehicle. This is particularly common with trucks, which often fill up before reaching their maximum allowable weight.

Further, different commodities have different handling requirements. Manufactured goods must be handled with greater care than bulk commodities such as coal or grain. Consequently, specialized equipment and operating procedures are used for some cargos, and this is reflected in energy requirements. Coal is often delivered directly to its final destination with the aid of highly automated rail or barge equipment. Many manufactured goods, in contrast, are handled through warehouses and delivered by local delivery trucks, a service that is less energy-efficient than full truckload service directly to the consignee. Further, high-value goods, such as most manufactured items, often require fast and particularly reliable service, resulting in greater energy use than would otherwise be the case. For example, railroads operate TOFC (trailer-on-flat-car) trains at much higher speeds than normal, with much greater use of energy per ton of cargo. The importance attached to speed also figures in the greater energy requirements for air transport as compared with other modes.

The analysis of freight energy requirements is also hindered by limitations of data. Virtually all freight service is provided by the private sector, and large segments of it are relatively unregulated. The number of operating companies is quite large, except for the airlines, thus greatly complicating data collection and making it difficult to reach a representative estimate of energy efficiency.

Given the wide variation in the characteristics of different freight modes, the requirements of particular commodities, and the influence of geography, there is no single, perfect summary measure of energy efficiency. Although cargo ton-miles (also called net ton-miles) make by far

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4/ Edward K. Morlok, "An Engineering Analysis and Comparison of Railroad and Truck Line-Haul Work (Energy) Requirements," presented at the Transportation Research Board Fifty-Fifth Annual Meeting, January 1976.



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the most useful measure of the output of freight transportation, they give greater than average weight to dense, bulk commodities and to longer hauls. Some analysts have argued for the use of a space-related measure, such as trailer miles. 5/ This might be particularly useful for comparing truck energy use with that of rail TOFC (trailers on flat cars) or COFC (containers on frame cars). It would avoid comparing the energy efficiency of all rail service including bulk goods with the energy efficiency of trucks, which carry predominantly manufactured goods. Of course, net ton-miles could still be used to compare similar services, such as rail TOFC versus truck.

Some analysts argue that any energy measure based on tonnage is biased since it does not reflect the different levels of service provided by each mode. Some have suggested as an alternative the amount of energy used per dollar of transportation expenditure or per dollar value of cargo. 6/ Again, their objection can be met by disaggregating total energy into the energy needed for bulk commodities and that needed for manufactured goods, together with an overall modal average. Such disaggregation is particularly important for railroads, since they carry both bulk and manufactured goods.

A similar suggestion is that the analysis be limited to movements of comparable commodities over comparable distances. 7/ The difficulty in this is that some modes cannot be compared in this way. Clearly, transcontinental rail movements cannot be compared with transcontinental barge movements.

Caution must therefore be used in interpreting the results of any study of average or overall energy efficiency. The results may be quite useful for debate over national policy, but may also be quite misleading if applied to particular circumstances.

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5/ American Trucking Association, Inc., "Debunking the Rail Energy Efficiency Myth" (January 1978).

6/ Samual Eastman, "Energy Intensiveness of Intercity Motor Common Carriage of General Freight: Its Measurement and the Effect of Federal Regulations," in Proceedings of the Transportation Research Forum (1976), p. 17. Eastman believes that this approach would show trucks as less energy-intensive than railroads.

7/ Samuel Eastman, "Circuity and the Energy Intensiveness of Inland Waterway and Rail Freight Transportation Systems: A Progress Report," paper presented to the Maritime Transportation Research Board, June 1978.

## CHAPTER III. ESTIMATED ENERGY EFFICIENCIES OF FREIGHT TRANSPORTATION MODES

Using the analytical framework from Chapter II, this chapter presents representative estimates for the principal components of energy use: propulsion energy, vehicle manufacturing energy, construction energy, maintenance energy, and circuity. 1/ Given the wide range of existing estimates for the energy use of each mode of transportation, it was necessary to use judgment in the selection of data. Rather than averaging various estimates together, typical or representative values were selected for each mode, taking into account the character of each source, including its apparent analytical quality. There is bound to be some disagreement over the estimates used. The analytical framework is straightforward, however, and readers can use their own judgment if they prefer to select different estimates.

### CALCULATION OF ENERGY EFFICIENCY

Table 1 presents estimates of the basic components of energy use for each of the six major modes of freight transportation. These estimates are discussed in detail in Appendix A. Several estimates are provided for rail, water, and air transportation. The rail estimates include an overall modal average and separate estimates for TOFC service and coal unit trains. TOFC (trailers on flat cars) represents the highest quality rail service, and also the most energy-intensive, while coal unit trains represent probably the most energy-efficient form of rail service, at least on a BTU-per-net-ton-mile basis. The barge estimates include, in addition to a modal average, estimates for upstream and downstream traffic in order to reflect obvious differences. Since air freight energy use varies greatly depending on whether all-cargo planes or combined passenger-freight planes are used, estimates for both are given.

Table 2 compares the relative importance of each component of energy use. In general, maintenance energy and the energy used in vehicle manufacturing and guideway construction are small relative to propulsion energy and the effect of circuity. For most modes, propulsion energy and circuity together account for more than three times the sum of the other

1/ No attempt was made to estimate access energy.

TABLE 1. ESTIMATES OF BASIC COMPONENTS OF ENERGY USE FOR SIX MODES OF FREIGHT TRANSPORTATION (In BTUs per net ton-mile)

| Mode | Propulsion Energy | Vehicle Manufacturing Energy | Construction Energy | Maintenance Energy | Circuity |
|---|---|---|---|---|---|
| Rail - Overall | 660 | 90 | 200 | 180 | 1.52 |
| TOFC | 1,000 | 80 | 200 | 140 | 1.44 |
| Unit coal train | 370 | 60 | 100 | 60 | 1.51 |
| Truck | | | | | |
| Average intercity | 2,100 | 100 | 300 | 300 | 1.22 |
| Barge - Overall | 420 | 40 | 50 | 30 | 1.83 |
| Upstream | 580 | 40 | 50 | 30 | 1.83 |
| Downstream | 220 | 40 | 50 | 30 | 1.83 |
| Air | | | | | |
| All-cargo plane | 26,250 | 150 | 100 | 750 | 1.05 |
| Belly freight | 3,570 | 20 | 20 | 100 | 1.05 |
| Oil Pipeline | 325 | 0 | 25 | 100 | 1.10 |
| Coal Slurry Pipeline | 1,000 | 0 | 50 | 100 | 1.10 |

SOURCE: Tables A-8, A-10, A-12, A-14, and A-16.

energy components. The fact that the others are relatively small helps to offset the much greater margin for error associated with estimating their magnitude.

## Operating Energy

Table 3 combines the energy components into three summary measures of energy efficiency. The first, operating energy, is simply propulsion energy adjusted for refinery losses and corresponds to what is usually meant

TABLE 2. RELATIVE IMPORTANCE OF BASIC COMPONENTS OF ENERGY USE FOR SIX MODES OF FREIGHT TRANSPORTATION (In percent of total modal energy)

| Mode | Propulsion Energy | Vehicle Manufacturing Energy | Construction Energy | Maintenance Energy | Circuity |
|---|---|---|---|---|---|
| Rail - Overall | 38 | 5 | 12 | 10 | 34 |
| TOFC | 49 | 4 | 10 | 7 | 30 |
| Unit coal train | 42 | 7 | 11 | 7 | 34 |
| Truck | | | | | |
| Average intercity | 61 | 3 | 9 | 9 | 18 |
| Barge - Overall | 42 | 4 | 5 | 3 | 45 |
| Upstream | 45 | 3 | 4 | 2 | 45 |
| Downstream | 35 | 6 | 8 | 5 | 45 |
| Air | | | | | |
| All-cargo plane | 92 | 1 | a/ | 3 | 5 |
| Belly freight | 92 | 1 | 1 | 3 | 5 |
| Oil Pipeline | 65 | 0 | 5 | 20 | 10 |
| Coal Slurry Pipeline | 79 | 0 | 4 | 8 | 9 |

NOTE: Totals may not add because of rounding.

a/ Less than 0.5 percent.

by the phrase "energy intensity." Measured by operating energy alone, the oil pipeline is the most efficient mode of freight transportation, followed by barge, rail, coal slurry pipeline, intercity truck, and airplane. Except perhaps for the coal slurry pipeline, where data are limited, this rank ordering of modes follows that of most other studies. It is notable that those modes with the greatest operating energy requirements (air and truck) also provide the highest speed and generally highest quality of service.

TABLE 3. SUMMARY MEASURES OF ENERGY EFFICIENCY FOR SIX MODES OF FREIGHT TRANSPORTATION (In BTUs per net ton-mile)

| Mode | Operating Energy a/ | Line-Haul Energy b/ | Modal Energy c/ |
|---|---|---|---|
| Rail - Overall | 660 | 1,130 | 1,720 |
| TOFC | 1,000 | 1,420 | 2,040 |
| Unit coal train | 370 | 590 | 890 |
| Truck | | | |
| Average intercity | 2,100 | 2,800 | 3,420 |
| Barge - Overall | 420 | 540 | 990 |
| Upstream | 580 | 700 | 1,280 |
| Downstream | 220 | 340 | 620 |
| Air | | | |
| All-cargo plane | 26,250 | 27,250 | 28,610 |
| Belly freight | 3,570 | 3,710 | 3,900 |
| Oil Pipeline | 325 | 450 | 500 |
| Coal Slurry Pipeline | 1,000 | 1,150 | 1,270 |

a/ Propulsion energy including refinery losses.

b/ Combines operating energy with maintenance energy, vehicle manufacturing energy, and construction energy.

c/ Adjusts line-haul energy for circuity, but not for access energy.

Among the more interesting modal comparisons: trucks require over three times as much operating energy per net ton-mile as do railroads as a whole, and over twice as much as the more directly competitive TOFC service. Railroads in turn require about 60 percent more operating energy per net ton-mile than do barges, although the more directly competitive rail services such as coal unit trains are, on average, probably slightly more energy-efficient. But operating energy includes less than half the total energy requirements for some modes--barge and rail, for example--and is therefore not a good basis for long-term comparisons.

## Line-Haul Energy

The second summary measure, called line-haul energy, adds to operating energy the energy required for maintenance, vehicle manufacturing, and the construction of guideways. When energy efficiency is measured in terms of line-haul energy, the transportation modes rank in the same order as with the operating energy measure, although the values are higher (Table 3). The differences are greatest for air freight (an increase of 1,000 BTUs per net ton-mile) and trucks (an increase of 700 BTUs per net ton-mile). The biggest percentage increase (about 70 percent), is for the rail mode--largely because propulsion energy requirements are relatively low for railroads.

While there is no shift in the overall ranking of the modes using the line-haul energy measure, some of the differences between them are smaller. Thus the coal slurry pipeline, which in terms of operating energy was about 60 percent less efficient than rail, is now only slightly less efficient. Also, within the rail mode, unit coal trains now appear slightly less energy-efficient than barges overall.

## Modal Energy

The third summary measure, modal energy, is the most comprehensive since it adjusts line-haul energy to take account of the extra energy required for circuity. Circuity is measured as a ratio of the distance actually traveled to the great-circle distance. This has a significant influence on overall energy efficiency. Barges, with the largest circuity (1.83), are affected the most, followed by rail (1.52).

Taking circuity into account results in a slightly different ranking of the transportation modes with oil pipeline first, followed by barge, coal slurry, rail, truck, and air. Coal slurry now appears more efficient than rail movement overall, though less so than coal unit trains--the most directly competitive rail service. The importance of circuity is clearly seen in its effect on the energy efficiency of the barge and rail modes: barge energy needs increase by 450 BTUs, more than the operating energy used, while rail energy needs increase by 590 BTUs, only slightly less than the operating energy used. The biggest absolute increase (1,360 BTUs) is for all-cargo planes, because of the very large propulsion energy required for that mode.